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3D RECONSTRUCTION OF ANATOMICAL SURFACES FROM UNORGANIZED RANGE DATA

G. Tognola[1], M. Parazzini[1], P. Ravazzani[1], C. Svelto[2], F. Grandori[1]
[1]CNR Center of Biomedical Engineering, c/o Polytechnic of Milan, Milan, Italy
[2] INFM-Department of Electronics and Information, Polytechnic of Milan and CNR-CSTS, Milan, Italy

Abstract-**Three-dimensional range data acquired through digital scanning of anatomical surfaces are used in this study as test material for the validation of an innovative approach for the reconstruction of closed surfaces. Although based on a straightforward theoretical approach, the proposed method exhibits an extreme accuracy in the reconstruction of a variety of target surfaces of different topologies. The method does not require any additional information about the target surface than the raw range data and is robust to noise. A triangular mesh approximates the target surface. Also, a few examples on the possible biomedical applications of the reconstructed surface are provided in this paper.**
***Keywords* - Surface reconstruction, range data, geometrical deformable model, triangular mesh**

I. INTRODUCTION

The problem of representing and reconstructing three-dimensional surfaces has been extensively addressed in the last 20 years. The ever increasing attention on this topic arises from many factors including the advances in 3D data-acquisition hardware (which have facilitated the acquisition of samples taken from a widespread variety of surfaces) and the practical importance that surface reconstruction has in many fields, such as medical imaging, surgical planning, graphics and vision research. In particular, surface reconstruction is of valuable use in the diagnosis and objective scoring of malformations, in monitoring progressive skeletal pathologies, and it is a valid tool during surgical planning.

All these fields require the interpolation of the measured samples with a continuous surface, usually a triangle mesh, to determine values at arbitrary positions that may be different from those already available or to measure quantitative parameters such as areas and volumes.

This paper is focused on the reconstruction of 3D closed surfaces. Many were the approaches proposed during the last decades to solve the problem of the reconstruction of closed surfaces (see, e.g., [1-3]). Most of these approaches are not straightforward, make use of a-priori knowledge (such as the shape and the elastic properties of the surface), or provide accurate results only for surfaces with specific features.

Aim of this study is the description of a new and simple approach for the adaptive reconstruction of a variety of 3D closed surfaces. Examples of reconstruction of anatomical surfaces will be given together with some possible biomedical applications.

II. METHODOLOGY

The target surface is approximated by a triangular mesh through an adaptive approach that locally minimizes an approximation error function. The error function gives a quantitative estimate of the accuracy of the reconstruction and is used here to obtain a non-uniform triangular mesh characterized by a greater density of triangles only in those regions of the surface where a greater resolution is needed.

The proposed method is based on a simple, topologically closed geometrical model [4] - an icosahedron - which is deformed to approximate the target surface. The geometrical model is placed within the volume contained by the range data and is progressively expanded to fit the surface, while maintaining its closed and locally simple (non-self-intersecting) nature.

The reconstruction algorithm is divided in three phases:

A. Phase one

The icosahedron is deformed by moving its set of vertices **V** towards the range data **P** along the direction of each vertex normal. Once the icosahedron has reached its maximum expansion, that is, when all its vertices are in proximity of the set of the range data, it is uniformly re-sampled by subdividing each face into four triangles. The added vertices of the re-sampled icosahedron are then moved again toward the range data as described before. At the end of this phase, a surface S’, first approximation of the target surface S is obtained.

B. Phase two

The surface S’ is locally re-sampled in order to obtained a surface S’’ rich in details. This is obtained by introducing new vertices in those regions of the surface S’ with a high local error. The local error determines the distance between the target surface S and the surface S’.

Given a point p and a surface S1, the distance between p and S1 is [5]:

$$d(p,S1) = \min d(p, p')$$

where $p' \in S1$ and $d(\cdot)$ is the Euclidean distance. The error E between two surfaces S1 and S2 is thus defined as [5]:

$$E(S1,S2) = \max d(p,S1)$$

where $p \in S2$.

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Abstract

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In our case, the points *p* and *p'* and the surfaces S1 and S2 are respectively the vertices **V** of the model, the range data **P**, the target surface S and the reconstructed surface S'.

The triangles of the surface S' are re-sampled only when the local error *E* exceeds a threshold value.

B. Phase three

The third phase removes the un-homogeneities of the surface S'' obtained in the second phase. This is achieved by smoothing the surface S'' with the iterative low pass filter proposed by Taubin [6]. In contrast to the classical Gaussian filter, the Taubin filter does not produce shrinkage of the surface.

While filtering, the vertices of the surface S'' are moved without changing the connectivity of the faces of the triangular mesh. At the end of the filtering process, a smoothed surface S''' is obtained from S''. The filtered surface has exactly the same number of vertices and faces as the surface S''.

III. RESULTS

As an example of the proposed method, Fig. 1 shows the set of unorganized range data obtained by 3D scanning of a head. The icosahedron that will be expanded and re-sampled to reconstruct the target surface is shown inside the volume delimited by the range data.

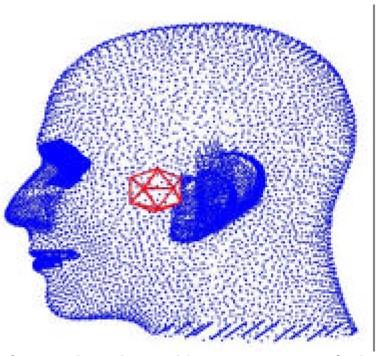

Fig. 1. The set of range data obtained by 3D scanning of a head (courtesy of Dr. H. Hoppe, http://research.microsoft.com/~hoppe/) and the icosahedron before the expansion of phase one.

Fig. 2 shows the surface S' obtained after the expansion and uniform re-sampling of the original icosahedron at the end of *phase one*. The surface S' is an initial, gross approximation of the target surface.

The reconstruction of spatial details of the target surface is achieved at the end of *phase two*, as displayed on Fig. 3. Note that the triangular mesh of the surface S'' thus obtained has a greater density of triangles in those regions more rich of spatial details such as the eyes, the nose, and the lips.

The triangular mesh of Fig. 3 is then filtered to eliminate the un-homogeneities of the surface S''. Fig. 4 shows the final reconstructed surface, as obtained at the end of *phase three*.

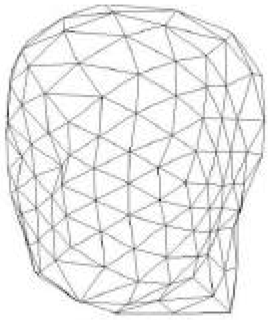

Fig. 2. *Phase one* - the surface S' obtained after the expansion and uniform re-sampling of the icosahedron of previous Fig. 1.

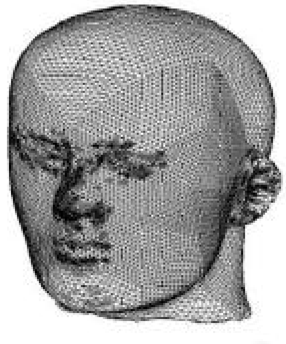

Fig. 3. *Phase two* – the surface S'' obtained by local re-sampling of surface S'.

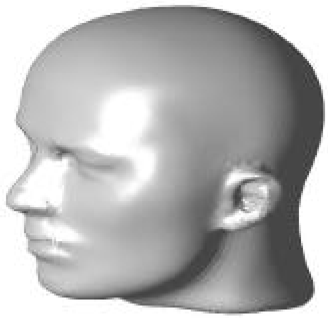

Fig. 4. *Phase three* – the final surface S''' at the end of the reconstruction process. This surface is obtained by smoothing the surface S'' of previous Fig. 3. Here, for rendering purposes, the triangles of the mesh surface S''' were uniformly colored and a spot light was added to the scene.

Another example of the reconstruction of anatomical surfaces is shown in Fig. 5, top panel: the surface was reconstructed using a set of range data acquired from the surface of a knee through laser scanning.

As shown on Fig. 6, the reconstructed 3D surface could be useful for the measurement of quantitative parameters. In particular, Fig. 6 gives an example of the extraction of the contour of a section of the knee at a generic z-level and the measurement of the cross-section area delimited by the contour.

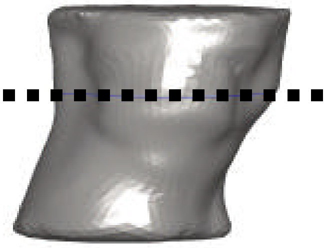

Fig. 5. The reconstructed surface of a knee (the range data used to reconstruct the knee surface were kindly provided by Cyberware). The dashed line indicates the position at a generic z-level of the cross-section reported in Fig. 6.

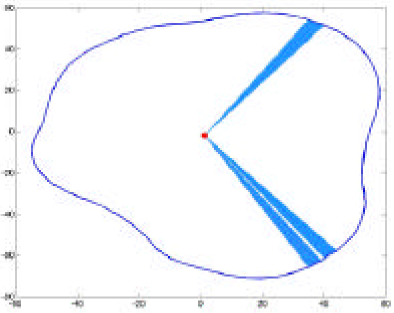

Fig. 6. The contour of the knee at the section level indicated by the dashed line in Fig. 5 and the measurement of the cross-sectional area delimited by the contour. To determine the cross-sectional area, the section was subdivided into small triangles and the areas of all the triangles were summed together.

IV. Conclusion

Based on the deformation and non-uniform re-sampling of a simple geometrical model, the method presented here is able to reconstruct 3D closed anatomical surfaces. The proposed approach is useful for a variety of closed surfaces and needs no additional information on the target surface to be reconstructed than the range data, that is the set of 3D points acquired over the surface through digital scanning. The result of the reconstruction process is a triangular mesh that optimally approximates the target surface.

The reconstruction is adaptive in the sense that the resulting triangular mesh locally minimizes an approximation error function that gives a quantitative estimate of the accuracy of the reconstruction. In this way, it is possible to obtain a non-uniform triangular mesh with a greater density of triangles only in those regions more rich of spatial details. As such, the proposed approach overcomes all the problems related to the manipulation and storage of redundant and very dense triangular meshes. Typically, huge triangular meshes need to be simplified in order to achieve a decimation of points, while maintaining a given accuracy in the reconstruction (for a survey of mesh simplification methods, see [7]).

The triangular mesh of the reconstructed anatomical surface can be used for the extraction of a variety of quantitative parameters of biomedical interest, such as the measurement of cross-sectional areas, inner volumes, and surface areas.

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